ENGINEERING CASE LIBRARY

Development of a Dynamic Seal at Beckman Instruments, Inc. - Spinco Division

Mr. Chet Arnessen*, a young graduate of San Jose State College and an employee of Beckman Instruments for the past several years, was asked to redesign part of the "buffer pump" of his company's Model 130 Spectrochrom Analyzer. A few of Beckman's customers had complained that the moving seals in this pump developed leaks after very little use; these complaints were reaching the company at the rate of one or two a month with some repeats. Beckman's customers were scattered all over the world and, since the Spectrochrom Analyzer is not portable, the company had to send its Field Service personnel to them to make whatever repairs were necessary.

Beckman Instruments

Beckman Instruments, Inc., has been manufacturing instruments for research and industrial use since 1935. The Spinco Division, located in Palo Alto, California, is a principal manufacturer and developer of instruments for biochemical and physiological research. Their instruments are used primarily for ultracentrifugation, electrophoresis, ion-exchange chromatography, microcalorimetry, viscometry, and biomedical measuring and monitoring.

All Beckman Spinco Division instruments are covered by a one year warranty which provides for both preventive maintenance and emergency service. The company's Field Service engineers are responsible for these operations. They instruct customers on the use of Beckman instruments, keep records of all repairs made on them, and make recommendations to the home office on improvements that they feel should be made.

* Fictitious Name

Prepared in the Design Division of the Department of Mechanical Engineering by William J. Clemens and David Horine under the direction of Professor H. O. Fuchs with financial support from the National Science Foundation.

The Spectrochrom Analyzer

The Model 130 Spectrochrom Analyzer, described in Exhibit 1, is primarily a research instrument employed in the analysis of certain biochemical materials One of the principal components of this instrument is a gradient buffer pump (Exhibit 2a) which mixes two buffer solutions and pumps the resultant mixture to the chromatograph column. The pump itself consists of three cam-driven plungers operating in cylinders where the buffer solutions, usually organic solvents such as acetic acid, ammonium acetate, and pyridene acetate, are mixed and pumped. The proportion of the two solvents in the mixture is regulated by an interchangeable program cam.

Soon after the first models of the Spectrochrom Analyzer were marketed, Beckman Instruments began to receive complaints that the plungers in the buffer pumps were leaking. The first few were repaired routinely in the field. As a pattern of failure became evident, the decision was made to review and redesign the moving seals associated with these plungers. It was at this time that Chet was assigned the problem.

Design Analysis

Chet began his work by systematically reviewing the design history of the buffer pump. What follows is a brief summary of his findings.

The plunger and cylinder used on the first breadboard design had been a glass hypodermic syringe (shown in Exhibit 3, along with the first stainless steel plunger) with an inside diameter of 0.351 inches. As the buffer solution evaporated, crystals deposited on the ground glass cylinder wall and the piston jammed.

Successive models were tested (see Exhibits 4 and 5) using a variety of piston and cylinder materials with o-ring seals. The most effective proved to be a smooth bore (honed to 4-6 min. finish) stainless cylinder with a stainless steel piston equipped with a Rulon[1] tip and a buna "N" o-ring. After evaluation by the Beckman Applications Research Section, this design was released for production.

Redesign

After he had acquainted himself with the design history of the pump, Chet examined the production model and talked with Field Service Department personnel in an attempt to determine the causes of failure. Most of the people he consulted felt that the problem lay in the type of seal chosen for the plunger. They found that the rubber o-ring was badly abraded on all of the pumps they had checked. There were several opinions expressed about the cause of this condition, but Chet thought that two modes of failure seemed most likely: 1) some of the organic solvents might be causing the o-rings to deteriorate; and 2) a thin film of fluid remaining on the cylinder wall might dry and leave an abrasive surface to wear down the o-rings.

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[1] "Rulon" is a trade name for a filled Teflon material that has higher wear resistance and less creep than pure Teflon.

Chet discovered that there was very little information available on small seals which could be directly applied to his project. Furthermore, he was unable to locate any seals of exactly the size he needed. "When I found there were no standard sized seals I could use," he explained, "I thought of changing the cylinder and plunger to a standard size, but that would have meant changing the stroke of the pumps in production and those already in the field. This would have been expensive, so we decided to retain the existing diameters on our redesign." While he was looking through one of the manufacturers' catalogues, he found that some data on o-ring performance and mounting recommendations were obtained by mathematically scaling the empirically derived data from one size of o-ring to fit a number of smaller ring sizes. From another manufacturer he learned that industrial recommendations for o-rings are usually acceptable for static seals, but they are not always applicable to dynamic sealing problems.

Chet designed a new cylinder and two plunger seals that did not require o-rings. He replaced the stainless steel cylinder with one of glass; unlike the original breadboard component, however, this cylinder had a precision bore (4-6 min. finish) inner surface.

The first of Chet's two plunger designs is shown in Exhibit 6. It consists of a Teflon tip attached to a "Kel-F"[2] plastic shank. Three "wiper rings" were machined into the Teflon tip to act as seals and guides. By providing an interference fit between the wiper rings and the glass cylinder, he hoped to minimize leakage past the inert Teflon. After three days of continuous testing, using water as the test solution, the wipers began to leak. Chet measured the outside diameters of the wipers and found that they had shrunk. This was apparently due to cold flowing of the Teflon.

Chet's second plunger seal redesign is shown in Exhibit 7. He had a "lip seal" machined into a Teflon tip which had an interference fit with the glass cylinder wall. This seal was intended to expand outward against the cylinder wall when pressure was applied to the chamber fluid. This design, however, began to leak soon after it was installed in the pump. Chet believed that this was due to cold flowing of the Teflon which had caused the lip seal to pull away from the chamber walls at low pressures.

Chet next tried o-rings made of Teflon. Since these rings could not be stretched into mounting grooves as could conventional rubber o-rings, they could not be tested on the existing steel plunger. Chet devised a test plunger (Exhibit 8) which would accommodate several types of Teflon rings. The Kel-F plastic tip of the plunger was threaded so that it could be screwed down against the o-rings to hold them on the plunger. A spiral Teflon wiper ring was mounted around the middle of the plunger to act as an additional guide and seal. Chet chose the spiral Teflon ring because 1) the Teflon would not swell upon contact with a buffer (as does rubber); and 2) a spiral ring could be installed on the shank of the plunger without the necessity of fabricating it to screw apart to accommodate an ordinary o-ring.

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[2] "Kel-F" is a trademark for a relatively inert plastic.

Chet tested three types of rings: a Teflon coated rubber ring, a slotted Teflon ring with a spring insert to provide a sealing force (Exhibits 7b and 7c), and a plain slotted Teflon ring. The Teflon coated rubber o-ring began to swell after two days of continuous operation. After disassembling the plunger, Chet found that the Teflon coating had worn off, thus exposing the base rubber to the buffer solution. The plain slotted o-ring began to cold flow and leaked soon after it was installed. The slotted ring with a spring insert leaked due to insufficient spring strength to affect sealing.

The seal Chet finally decided upon is the Sealpruf[3] Kap Seal shown in Exhibit 9. It makes use of a Teflon cap for the sealing surface and an inner synthetic rubber o-ring that forces the Teflon cap against the cylinder wall. Instead of allowing a clearance between the plunger groove and the seal as the manufacturer recommended for normal sealing problems (Exhibit 9), Chet screwed the plunger cap against the ring as shown in Exhibit 10a. In this design, the Teflon is contained by the mounting slot and thereby prevented from cold flowing.

Chet life-tested the Kap Seal for a month before turning it over to production. The final design, shown in Exhibit 10, was subsequently passed by the Applications Research Section and put into final production. After almost one year in service, no serious flaws in the pump have been reported.

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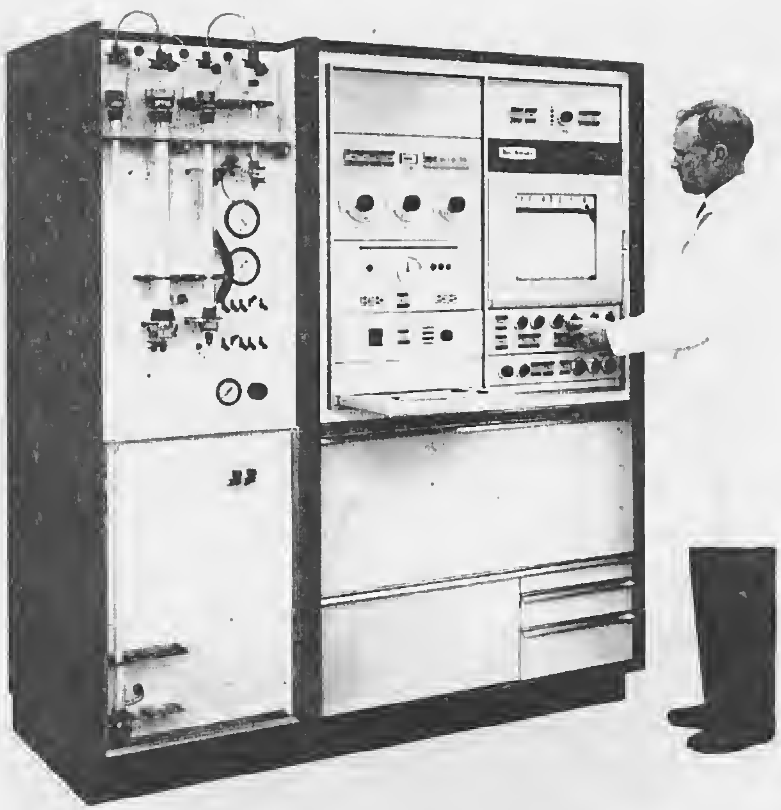
[3] Fictitious name.

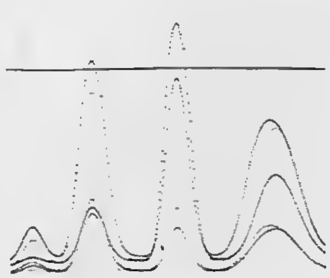


Model 130 Spectrochrom® Analyzer

The Spectrochrom Analyzer offers a complete facility for column chromatography in one instrument . . . providing automated analyses of proteins, peptides, nucleic acids and their derivatives, and other biochemical materials. In a single run, with little or no operator supervision, it prints out data that formerly required many time-consuming consecutive runs, and much supervision. Thus the Spectrochrom can simplify chromatographic research programs, and extend and amplify them as well.

With its inter-related combination of components, the Spectrochrom enables the operator to vary selectively the common parameters of a chromatographic analysis until ideal conditions are established. These can then be reproduced faithfully in following runs.

The sample can be studied at wavelengths that best suit its absorption pattern—e.g., nucleic acid derivatives at 250, 260 and 280 mμ. pH and conductivity gradients can be both programmed and monitored, with readings printed out on the recorder chart for correlation with absorption peaks. The recorder chart is keyed by an event marker to the collected fractions, which are held under refrigeration ready for further analysis.



Major Components

Jacketed analytical or preparative columns can be mounted on the Model 130, and cooled or heated from 4° to 75°C. Quick-disconnect fittings permit fast column interchange.

Buffer gradients are supplied by Beckman-designed buffer pump, with gradient programmed by the operator as desired.

Effluent pH and conductivity monitors provide a printed record of these measurements—facilitating the choice of operating conditions.

Dual-beam spectrophotometer automatically scans column effluent at choice of three wavelengths from 220 to 750 mμ; two cuvette path lengths provide excellent sensitivity for a wide range of sample concentrations.

10-Channel recorder provides six color-coded curves of effluent absorbance; two other channels are for pH and conductivity monitoring, leaving two for auxiliary uses.

Refrigerated fraction collector contained in the Spectrochrom Analyzer is the Model 132 Collector described on the following page. It is held in a refrigerated drawer that keeps the collected fractions cold.

Controls permit the programming of a change of column temperature, change of buffer, and instrument shut-down. Panel connections and a valving system allow column effluent to be diverted through an auxiliary instrument and back to the Model 130's analytical system.

318003 Model 130 Spectrochrom Analyzer, 68″ x 30″ x 76″ high, with gradient pump, spectrophotometer, pH and conductivity meters, flowmeter, fraction collector, and controls.

Exhibit 1.

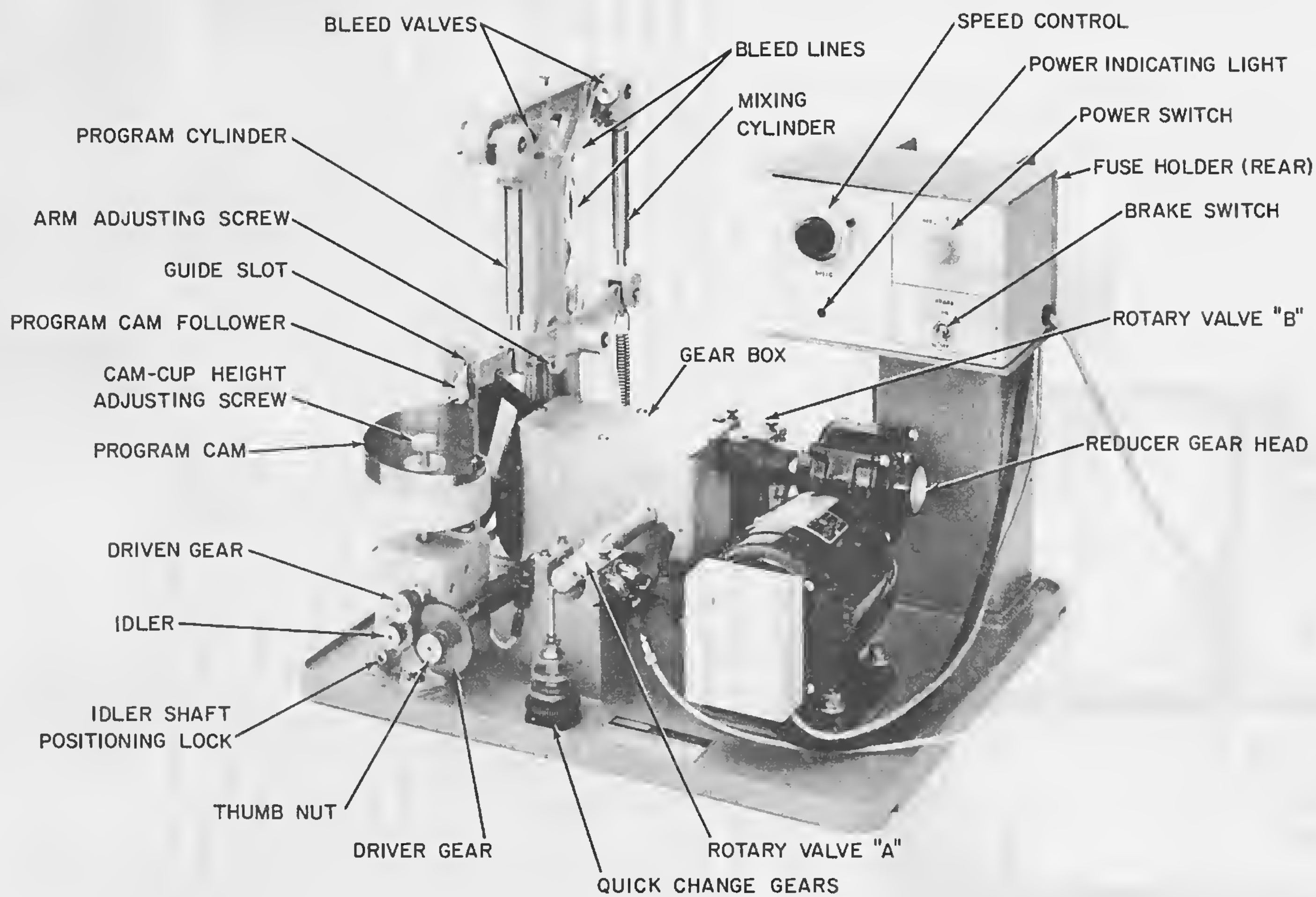


Exhibit 2a. Gradient Buffer Pump

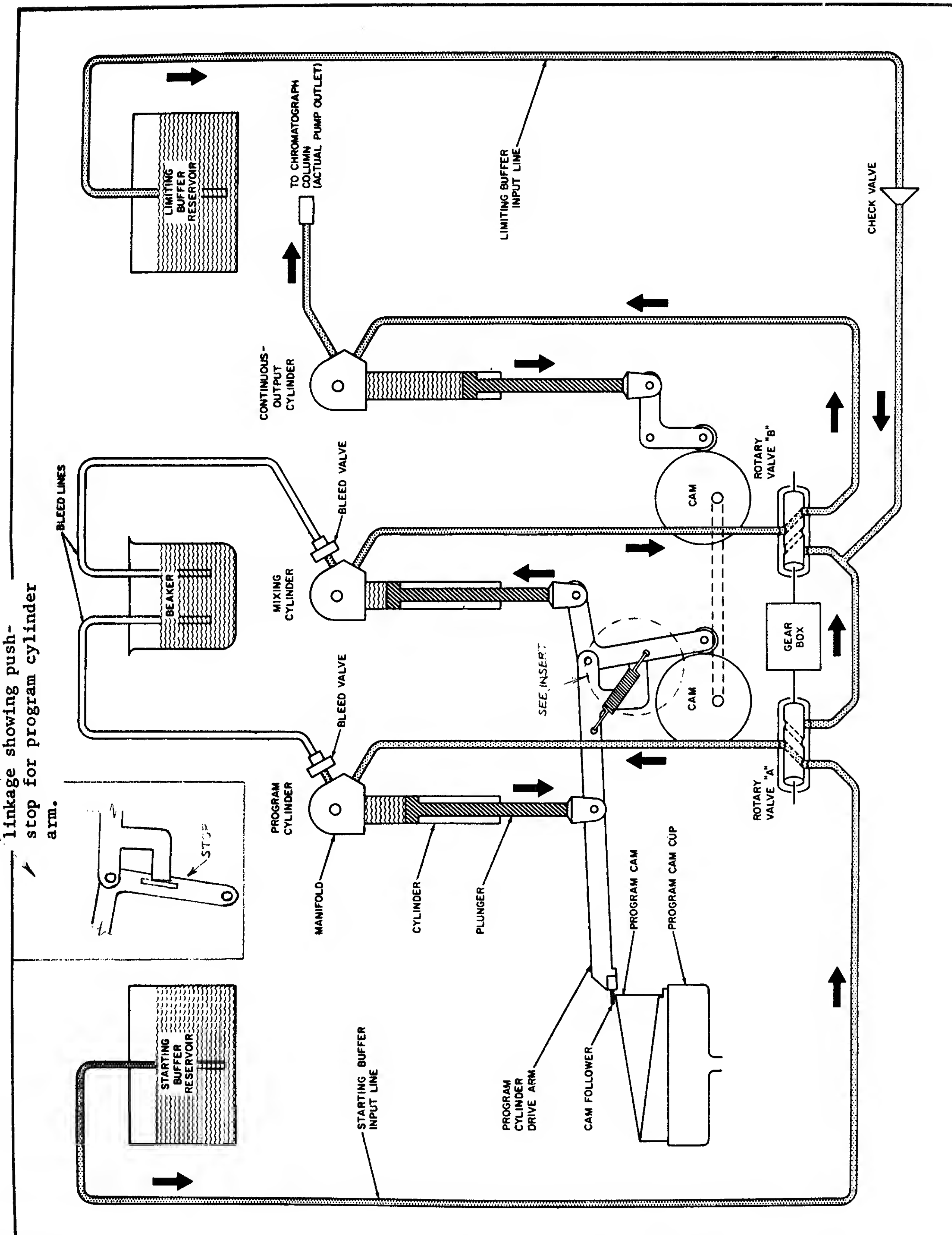


Exhibit 2b. Buffer Pump Flow Diagram

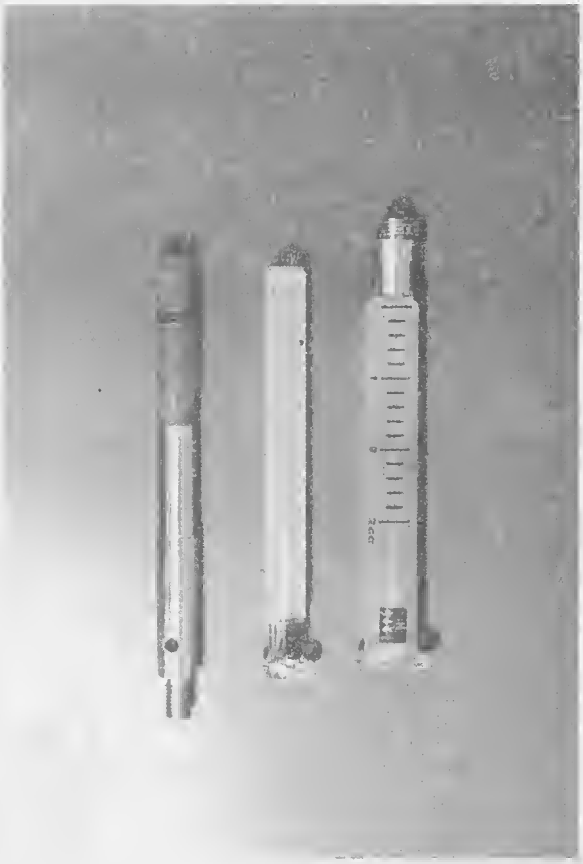


Exhibit 3. Hypodermic syringe, showing glass cylinder, glass plunger, and first stainless steel plunger.

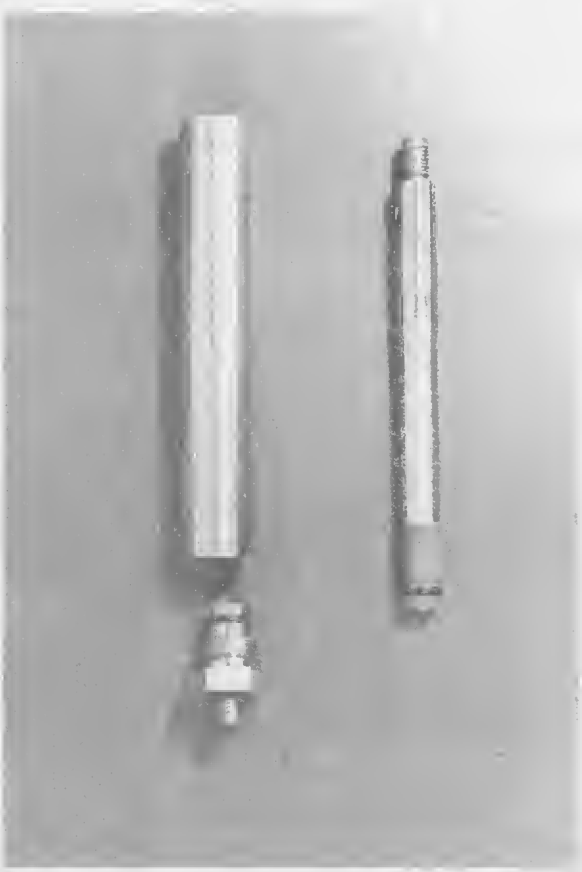


Exhibit 4. First production model stainless steel cylinder and plunger. Hexagon fitting was added to make cleaning easier. A "Rulon" insert was added as shown in Exhibit 5 to provide a second contact surface for the plunger to ride on.

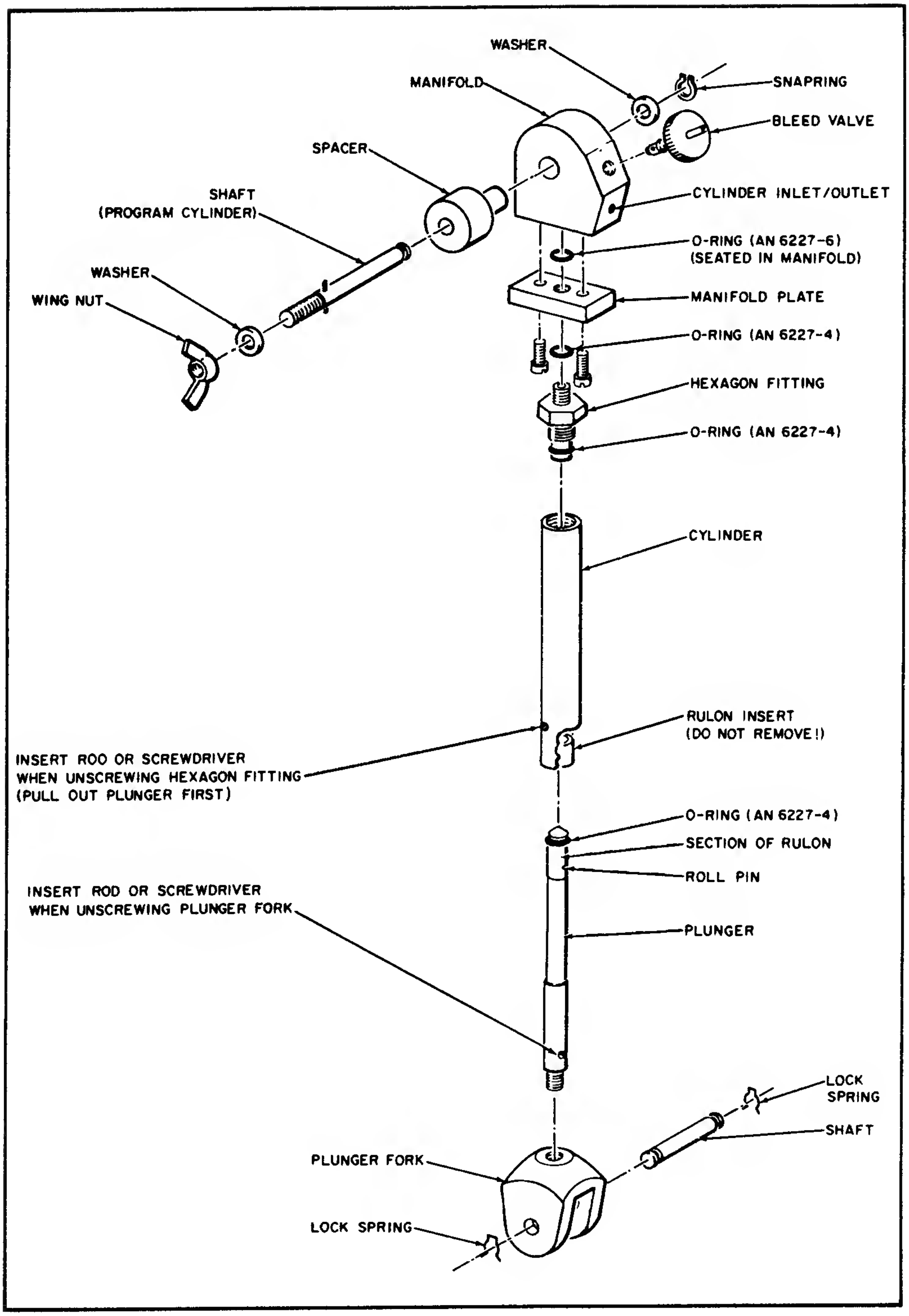


Exhibit 5. Exploded view drawing of cylinder and plunger shown in Exhibit 4.

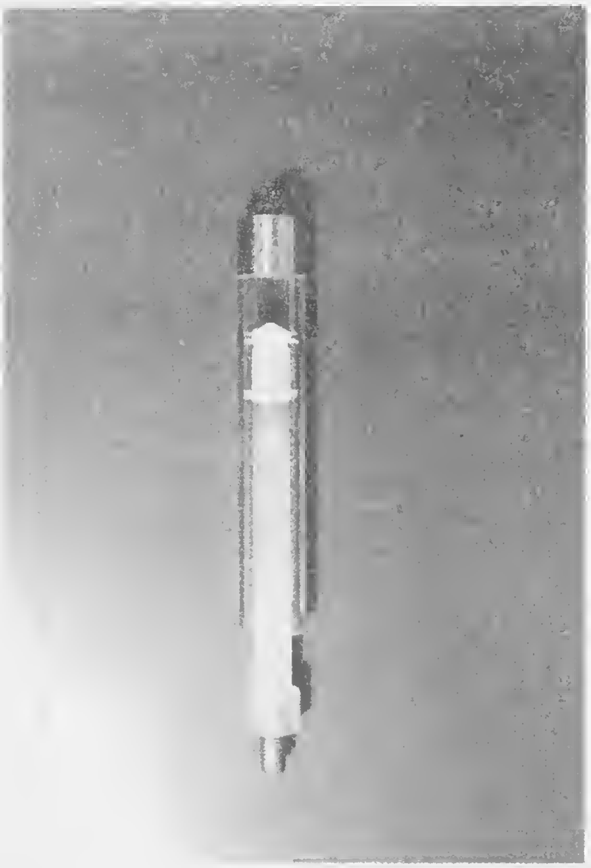
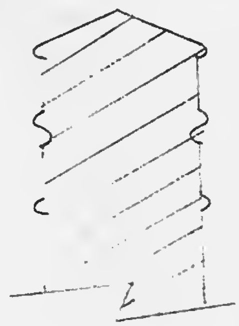


Exhibit 6. "Wiper ring" plunger seal design. Rings are machined on the Teflon tip as shown on the sketch below.



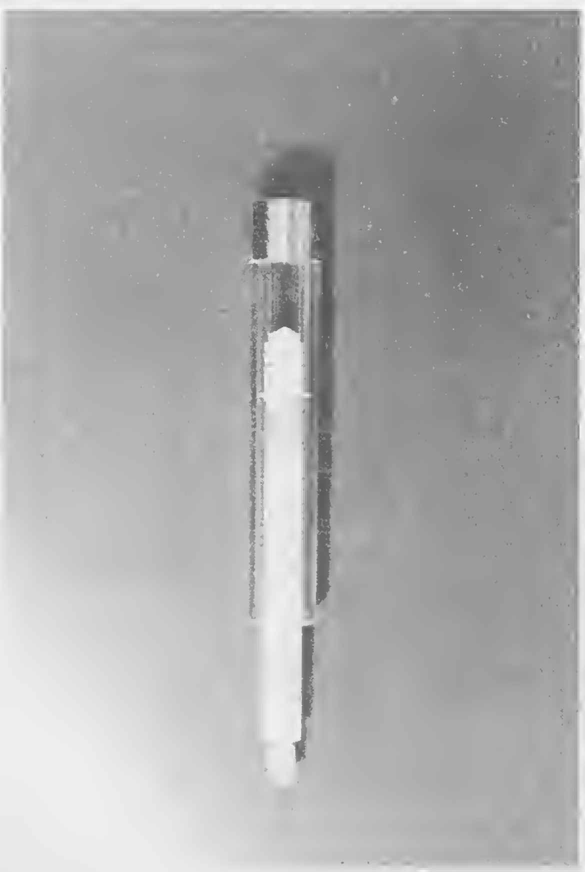
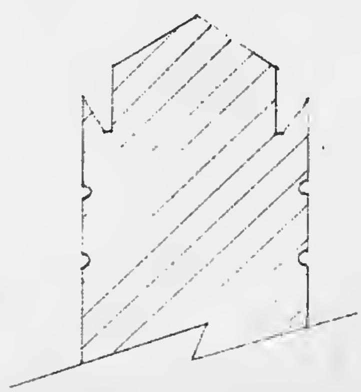


Exhibit 7. So-called "lip seal" plunger seal design. A cross-section of the Teflon tip is shown below.



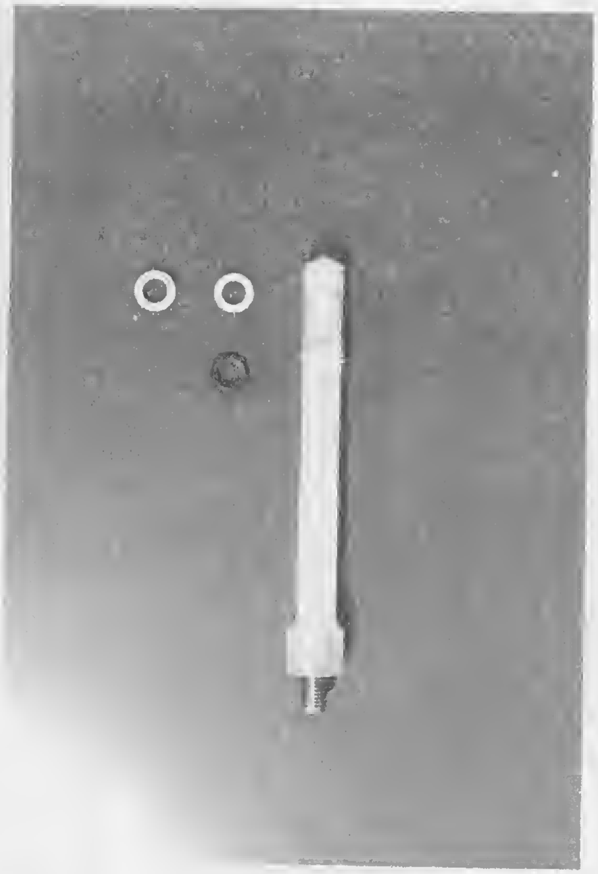


Exhibit 8a. Assembled test plunger. Note the spiral wiper ring installed below the plunger tip. Some of the sealing rings tested are, from left to right, top to bottom, a slotted Teflon ring with a spring insert, a pure Teflon o-ring, and a Teflon coated rubber o-ring.

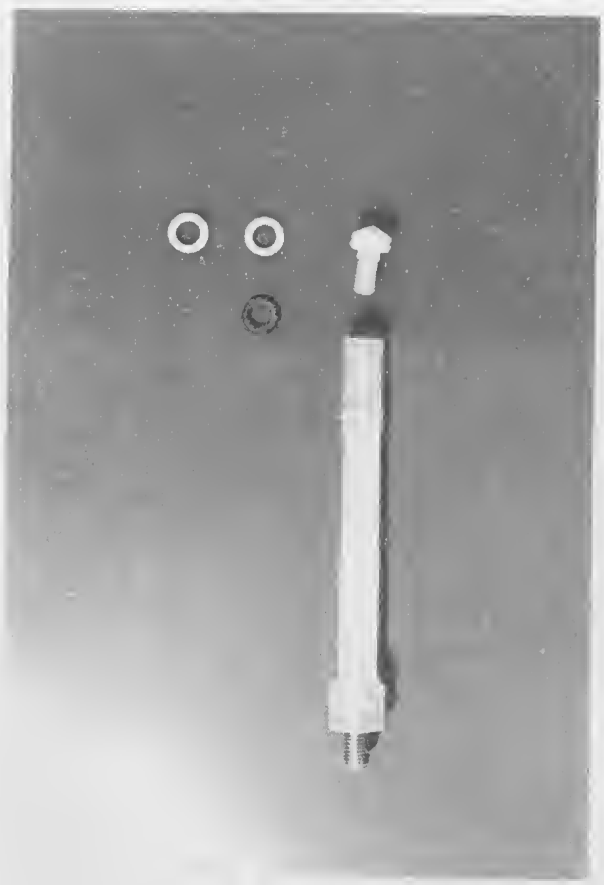


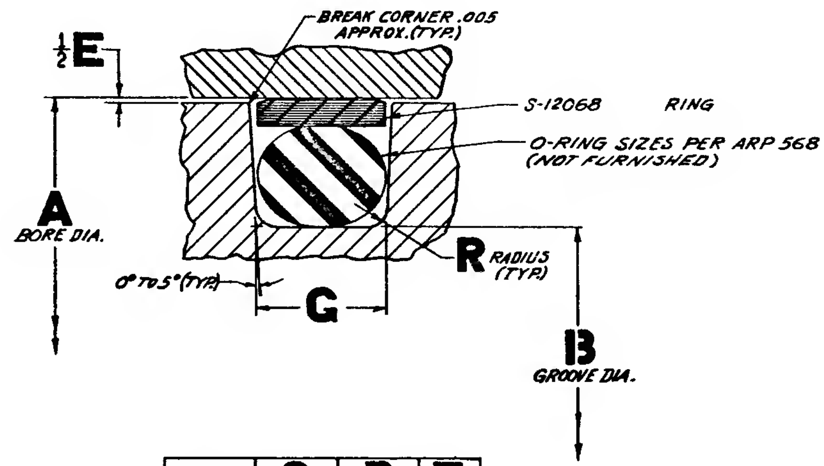
Exhibit 8b. Disassembled test plunger. Screw-on tip was necessary because Teflon rings would not stretch over the plunger for mounting in a conventional groove.

Exhibit 8. Test plunger; identical in form to final plunger design.

DASH NO.	A DIA.	B DIA.	O-RING DASH NO. SEE NOTE #2
	+.001 -.000	+.000 -.001	
006	.235	.108	005
007	.266	.123	006
008	.297	.154	007
009	.329	.185	008
010	.360	.217	009
011	.422	.248	010
012	.485	.310	011
	+.002 -.000	+.000 -.002	
013	.550	.373	012
014	.613	.438	013
015	.675	.501	014
016	.738	.563	015
017	.800	.626	016
018	.863	.688	017
019	.925	.751	018
020	.993	.813	019
021	1.055	.881	020
022	1.118	.943	021
023	1.180	1.006	022
024	1.243	1.068	023
025	1.305	1.131	024
026	1.368	1.193	025
027	1.430	1.256	026
028	1.493	1.318	027
111	.613	.373	110
112	.676	.435	111
113	.738	.498	112
114	.801	.560	113
115	.863	.623	114
116	.926	.685	115
117	.993	.748	116
118	1.056	.815	117
119	1.118	.878	118
120	1.181	.940	119
121	1.243	1.003	120
122	1.306	1.065	121
123	1.368	1.128	122
124	1.431	1.190	123
125	1.493	1.253	124
126	1.558	1.315	125
127	1.620	1.380	126
128	1.683	1.442	127
129	1.742	1.505	128
130	1.805	1.564	129
131	1.867	1.627	130
132	1.930	1.689	131
133	1.992	1.752	132
134	2.055	1.814	133
135	2.118	1.877	134

DASH NO.	A DIA.	B DIA.	O-RING DASH NO. SEE NOTE #2
	+.002 -.000	+.000 -.002	
136	2.180	1.940	135
137	2.243	2.002	136
138	2.305	2.065	137
139	2.368	2.127	138
140	2.430	2.190	139
141	2.493	2.252	140
142	2.555	2.315	141
143	2.618	2.377	142
144	2.680	2.440	143
145	2.743	2.502	144
146	2.805	2.565	145
147	2.868	2.627	146
148	2.930	2.690	147
149	2.993	2.752	148
211	1.053	.748	210
212	1.116	.810	211
213	1.178	.873	212
214	1.241	.935	213
215	1.303	.998	214
216	1.366	1.060	215
217	1.428	1.123	216
218	1.491	1.185	217
219	1.553	1.248	218
220	1.616	1.310	219
221	1.678	1.373	220
222	1.741	1.435	221
223	1.868	1.498	222
224	1.993	1.625	223
225	2.118	1.750	224
226	2.243	1.875	225
227	2.368	2.000	226
228	2.493	2.125	227
229	2.618	2.250	228
230	2.743	2.375	229
231	2.868	2.500	230
232	2.993	2.625	231
233	3.118	2.750	232
234	3.243	2.875	233
235	3.368	3.000	234
236	3.493	3.125	235
237	3.618	3.250	236
238	3.743	3.375	237
239	3.868	3.500	238
240	3.993	3.625	239
241	4.118	3.750	240
242	4.243	3.875	241
243	4.368	4.000	242
244	4.493	4.125	243
245	4.618	4.250	244

DASH NO.	A DIA.	B DIA.	O-RING DASH NO. SEE NOTE #2
	+.002 -.000	+.000 -.002	
246	4.743	4.375	245
247	4.868	4.500	246
326	1.995	1.498	325
327	2.120	1.623	326
328	2.245	1.748	327
329	2.370	1.873	328
330	2.495	1.998	329
331	2.620	2.123	330
332	2.745	2.248	331
333	2.870	2.373	332
334	2.995	2.498	333
335	3.120	2.623	334
336	3.245	2.748	335
337	3.369	2.873	336
338	3.494	2.997	337
339	3.619	3.122	338
340	3.744	3.247	339
341	3.869	3.372	340
342	3.994	3.497	341
343	4.119	3.622	342
344	4.244	3.747	343
345	4.369	3.872	344
346	4.494	3.997	345
347	4.619	4.122	346
348	4.744	4.247	347
349	4.869	4.372	348
	+.003 -.000	+.000 -.003	
426	5.099	4.497	425
427	5.224	4.622	426
428	5.349	4.747	427
429	5.474	4.872	428
430	5.599	4.997	429
431	5.724	5.122	430
432	5.849	5.247	431
433	5.974	5.372	432
434	6.099	5.497	433
435	6.224	5.622	434
436	6.349	5.747	435
437	6.474	5.872	436



DASH NO.	G GROOVE WIDTH	R	E MAX.
	+.005 -.000		
006 TO 012	.079	.005/.015	.004
013 TO 028	.079	.005/.015	.005
111 TO 149	.112	.005/.015	.005
211 TO 247	.149	.010/.025	.006
326 TO 349	.221	.020/.030	.007
426 TO 437	.297	.020/.030	.010

NOTES:-

1. DASH NUMBERS OF THIS DWG. CORRESPOND TO DASH NUMBERS OF ARP 568 UNIFORM DASH NUMBERING SYSTEM FOR O-RINGS.
2. O-RING DASH NUMBERS ARE SHOWN FOR SIZE DESIGNATION ONLY. SELECTION OF O-RING ELASTOMERIC COMPOUND SHOULD BE MADE TO SUIT THE FLUID AND TEMPERATURE ENVIRONMENT OF THE HYDRAULIC OR PNEUMATIC SERVICE IN WHICH THE SEAL WILL BE USED.
3. THE SERIES "B" RING IS FURNISHED IN WEAR RESISTANT TURCON (TFE COMPOUND PER SPEC. ZZ-53) THE SERIES "B" RINGS ARE ALSO FURNISHED IN OTHER TFE MATERIALS UPON REQUEST.
4. ALL DIMENSIONS SHOWN ARE IN INCHES.
5. BORE DIAMETERS ARE PER MIL-P-5514 D.

S-12068 D

Exhibit 9. Sealpruf Kap Seal Description.

MATERIAL, SIZE AND DESCRIPTION

[redacted]

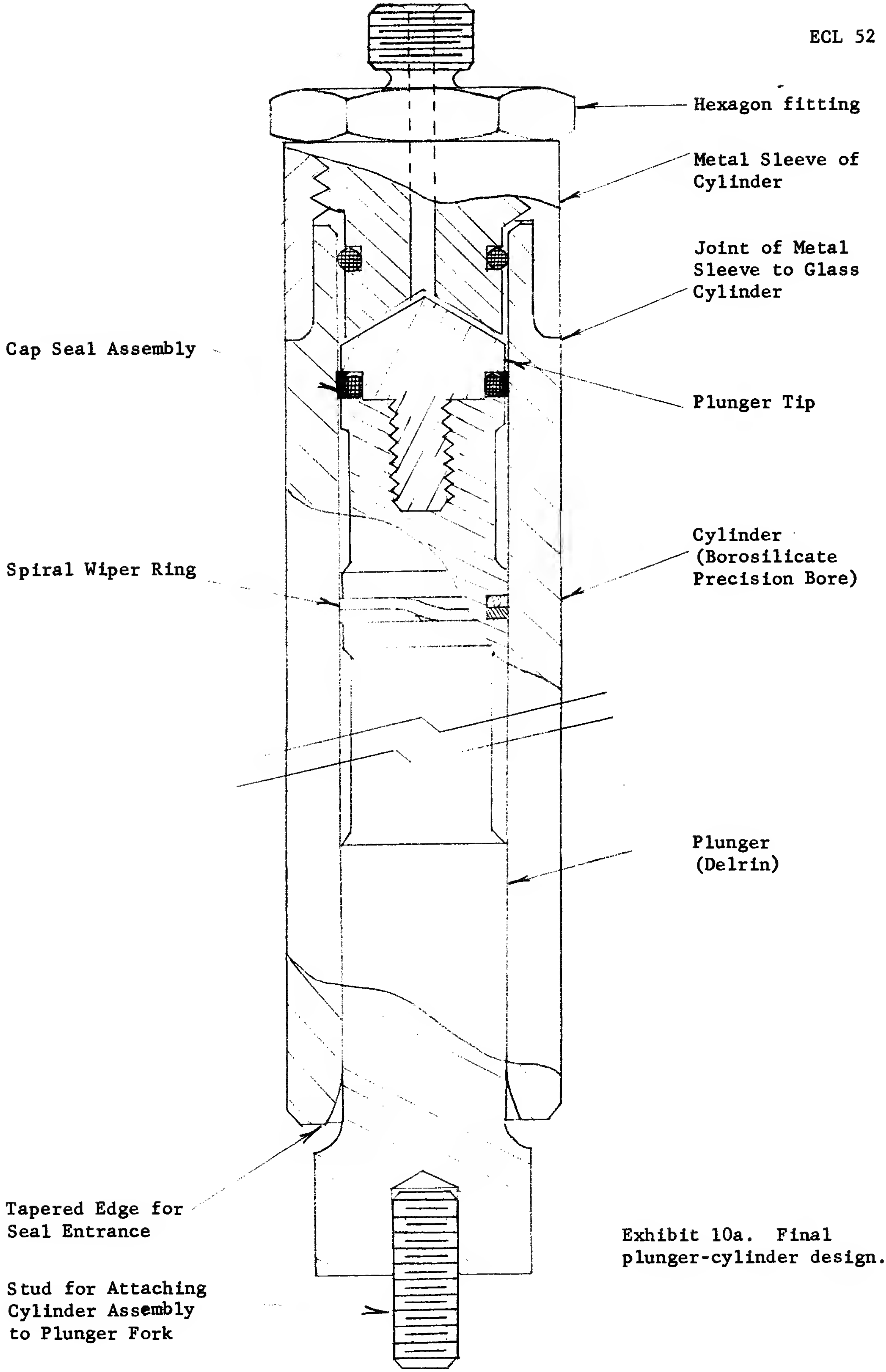


Exhibit 10a. Final plunger-cylinder design.

Exhibit 10b. Final plunger and cylinder assembly.

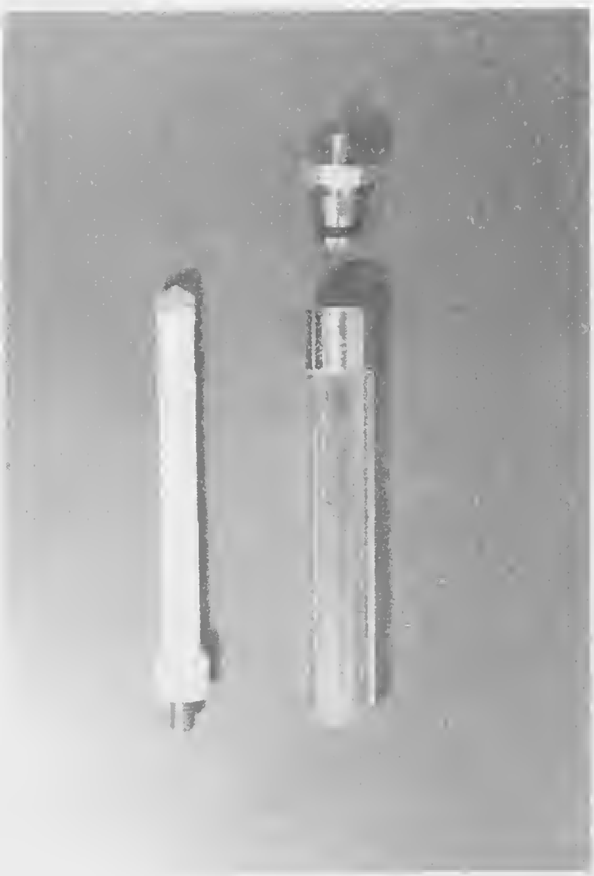


Exhibit 10c. Disassembled plunger-cylinder unit. Seal used here is the Sealpruf Kap Seal.